АСТРОФИЗИКА

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FIRST LIGHT CURVE MODELLING OF ECLIPSING BINARY SYSTEMS V1264 Cas, V0664 Lac AND GSC 0199-2035

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Photometric analysis for the newly discovered systems V1264 Cas, V0664 Lac and GSC 0199-2035 were carried out using the most recent version of the Wilson-Devinney binary star modeling code (WD) based on model atmospheres by Kurucz. Accepted models revealed physical parameters use to adopt the spectral type of the components of the studied systems. Locations of the systems on the theoretical mass-luminosity and mass-radius relations revealed good fit for all the systems components except for the secondary components of the systems; V1264 Cas and GSC 0199-2035 where they lie above the TAMS track.

Keyword: *eclipsing binaries: light curve modelling: evolutionary state*

1. *Introduction*. Eclipsing binary systems are one of the variable stars groups which have a light curves shape that depends on the physical properties of the systems components and geometrical configuration (Hilditch [1]). The shapes of the binary components described and classified (detached-semidetached-contact) according to Roche geometry which depending on the degree of filling Roche lobe (Prša [2]). Orbital solutions for new discovery systems of eclipsing binary type are the main sources of knowledge about their physical and geometrical properties which reveal, among other solutions, relative dimensions of stars; their orbital inclination, effective temperatures, the eccentricity of the orbit, and potential spots. Combined orbital solutions using photometric observations together with radial velocities obtained from spectroscopic observations, reveal masses of the components, and radii. The estimated physical parameters for the eclipsing binary systems are of great importance in studies related to their stellar structure and evolution. In this paper we used an extensive photometric data to perform a comprehensive study of three newly discovered eclipsing binary systems: V1264 Cas, V0664 Lac and GSC 0199-2035. The variability of the discovered systems was detected for the first time during observations of other eclipsing binaries.

The structure of this paper is as follows: in Section 2 we display the basic information about the studied systems, Section 3 is devoted to the light curve modeling, and in Section 4 we discuss the evolutionary status of the studied

systems. Summary of the results and conclusion are outlined in Section 5.

2. *Observations.*

2.1. *V1264 Cas.* The system V1264 Cas was announced as variable star with period of $0^d.30408$ ($V = 14^m.80$) by Liakos and Niarchos [3] and listed as eclipsing binary of W UMa type (overcontact) in the AAVSO data base. It was discovered inside the field of view of the known variable star V364 Cas. The observations were carried out at the Gerostathopoulion Observatory of the University of Athens in the period from 2007 to 2009, using a 40-cm Cassegrain telescope equipped

Table 1

BASIC INFORMATION OF THE VARIABLE, COMPARISON, AND CHECK STARS

Star Name	α (2000.0)	δ (2000.0)	*B*	*V*	*B-V*
Variable (V1264 Cas)	$00^h51^m18^s.54$	+50°22'28".11	15.51	14.80	0.71
Comparison (GSC 3270-01412)	$00^h51^m41^s.05$	+50°22'52".32	12.64	--	--
Check (GSC 3270-00210)	$00^h51^m39^s.86$	+50°20'31".02	13.04	--	--
Variable (V0664 Lac)	$22^h14^m03^s.68$	+48°35'17".90	14.40	13.70	0.70
Comparison (USNO-A2.0 1350-16135725)	$22^h14^m10^s.32$	+48°37'47".78	12.84	--	--
Check (USNO-A2.0-1350-6139130)	$22^h14^m10^s.32$	+48°37'47".78	12.84	--	--
Variable (GSC 0199-2035)	$08^h07^m31^s.00$	+01°59'43".50	12.01	11.29	0.72
Comparison (GSC 0194-0498)	$08^h07^m35^s.88$	+01°56'06".29	10.69	10.13	0.56
Check (GSC 0194-0292)	$08^h07^m00^s.62$	+01°47'15".53	11.12	10.51	0.61

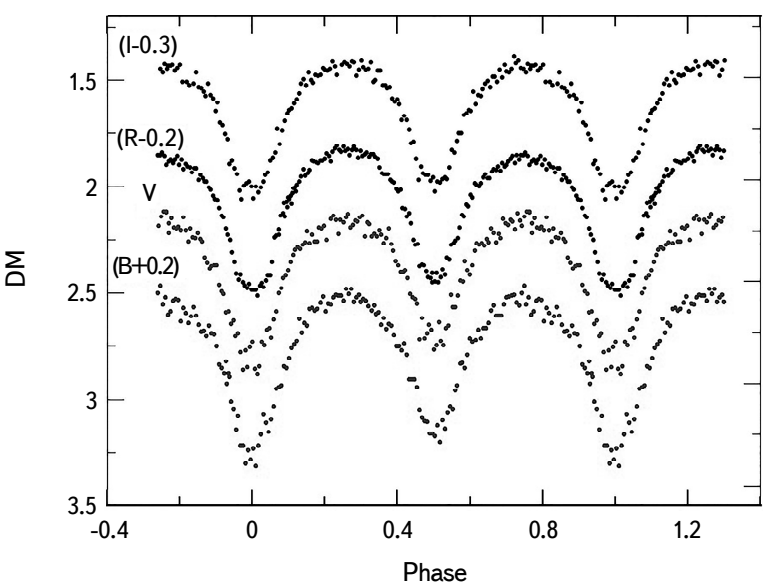

Fig.1. Observed light curves for the system V1264 Cas.

with ST-8XMEi and ST-10XME CCD cameras and the BVRI Bessell photometric filters. The stars GSC 3270-01412 and GSC 3270-00210, indicated in the finding chart, were used as comparison and check stars, respectively, during the observations. Table 1 lists their basic information while Fig.1 presents observed light curves in BVRI pass bands. The differential magnitudes were obtained for all systems using the software Muniwin v.1.1.26 (Hroch [4]). The shape of the observed light curve indicates typical W UMa (EW) eclipsing binary (MaxI - MinI $= -0^m.67$) and (MaxI - MinII $= -0^m.60$) in R filter. We used Equation (1) which represents the ephemeris adopted by Liakos and Niarchos [3] to calculate the individual phases of all observational data.

$$\text{MinI} = \text{HJD } 2455140.263 + 0.30408\,E\,. \tag{1}$$

2.2. *V0664 Lac*. The system V0664 Lac ($P = 0^d.65321$) was observed and reported as a variable star of Beta Lyrae type (semidetached) by Liakos and Niarchos [5]. The system was discovered in the field of view of the system AU Lac and observed in the period from Aug 29 to Dec 6, 2010 using $0^m.4$ Newtonian f/5.1 telescope equipped with SBIG ST-10XME CCD camera and the VI Bessell photometric filters, at the University of Athens Observatory. The stars USNO-A2.0-1350-16135725 and USNO-A2.0-1350-16139130 were used as a comparison and check stars, respectively, during the observations. The coordinates of the variable, comparison, and check stars are listed in Table 1, while Fig.2 displays the observed light curves in VI Bessell pass bands. Equation (2), represents the ephemeris adopted by Liakos and Niarchos [3] was used to calculate the individual phases of all observational data.

$$\text{MinI} = \text{HJD } 2455538.316 + 0.65321\,E\,. \tag{2}$$

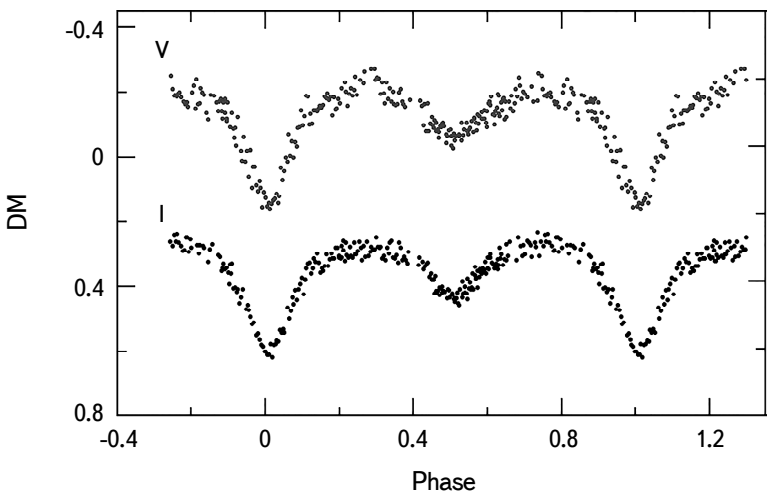

Fig.2. Observed light curves for the system V0664 Lac.

2.3. *GSC 0199-2035.* The variability of the system GSC 0199-2035 was discovered by Liakos and Niarchos [6], the system was classified as a detached system (EA) with a period of $P = 1^{d}.012714$. First observations for the system were carried out in period from February 4 to March 29, 2010 in B and R pass bands using $0^{m}.2$ reflector f/5 telescope of the National and Kapodistrian University of Athens observatory supplied with SBIG ST-8XMEi CCD camera and BR Bessell photometric filters. They used GSC 0194-0498 and GSC 0194-0292, with coordinates listed in Table 1, as a comparison and check stars, respectively, during their observations. The variability of the system GSC 0199-2035 was discovered in the field of variable stars YY CMi and BI CMi. Fig.3 displays the observed light curve in BR (Bessell) pass bands, where the individual phases of the curves were calculated using the ephemeris of Equation (3), adopted by Liakos and Niarchos [6]:

$$\text{MinI} = \text{HJD } 2454933.536 + 1.012714\,E\,. \tag{3}$$

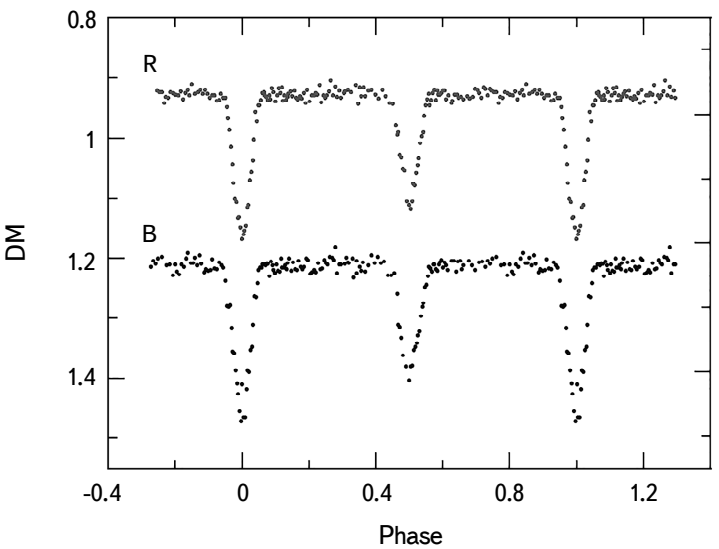

Fig.3. Observed light curves for the system GSC 0199-2035

3. *Light curve modelling.* Orbital elements determination and light curve analysis for the systems V1264 Cas, V0664 Lac and GSC 0199-2035 were performed by means of windows interface version of Wilson-Devinney binary star modeling (WD) code [7], which apply model atmosphere of Kurucz [8]. The adopted theoretical model reveals absolute parameters and synthetic light curves similar to the observed ones. The colour index (B-V) of the studied systems listed in SIMBAD (http://simbad.u-strasbg.fr/simbad/) were used to estimate their primary stars temperatures T_1 by means of colour index temperature relation by

Takunaga [9]. The adopted primary stars temperatures were used as initial values in the light curve modelling. All individual observations of the observed light curves in each band were analyzed. We adopted gravity darkening and bolometric albedo exponents for convective envelopes ($T_{eff} < 7500$ K), where $A_1 = A_2 = 0.5$, Rucinski [10]) and $g_1 = g_2 = 0.32$, Lucy [11]. The logarithmic limb darkening coefficients were interpolated from the tables of Van Hamme [12]. The initial values of the mass ratio q was adopted by means of q-search technique, which assumed mass ratios q with the values ranging from 0.10 to 0.90 using the adopted mode for each system. The convergent solution implies sums of the squared deviations $\Sigma(O-C)^2$ for each assumed q value which are plotted in Fig.4a, b, c for the studied systems. The adopted q values for each system corresponding to the minima of $\Sigma(O-C)^2$ which are used as initial values in the system modelling runs. Each system was fitted with model containing seven free parameters: orbital inclination i, photometric mass ratio q, surface potentials of both components Ω_1 and Ω_2, effective temperatures of the primary and secondary component T_1 and T_2, and

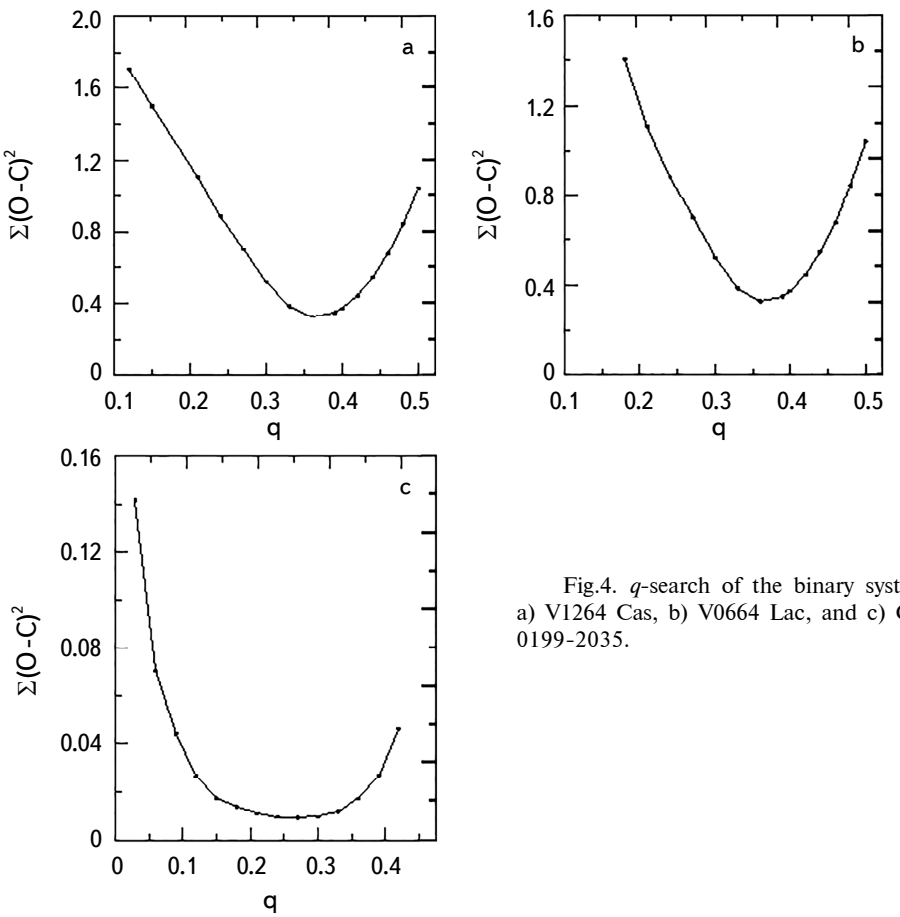

Fig.4. q-search of the binary systems: a) V1264 Cas, b) V0664 Lac, and c) GSC 0199-2035.

Table 2

PHOTOMETRIC SOLUTIONS FOR THE SYSTEMS V1264 Cas, V0664 Lac AND GSC 0199-2035

Parameter	V1264 Cas	V0664 Lac	GSC 0199-2035
i (°)	82.94±0.44	68.78±0.20	78.82±0.07
$g_1 = g_2$	0.32	0.32	0.32
$A_1 = A_2$	0.5	0.5	0.5
q (M_2/M_1)	0.4063±0.0022	0.7118±0.0049	0.2653±0.0010
Ω_1	2.5974±0.0067	3.7042±0.0128	4.3913±0.0048
Ω_2	2.5974±0.0067	3.5147±0.0132	3.1323±0.0105
T_1, K	5028±17	5702±57	5004±8
T_2, K	4880±6	4415±5	4748±5
Ω_{in}	2.6908	3.2640	2.3881
Ω_{out}	2.4433	2.8565	2.2215
r_1 pole	0.4491±0.0034	0.3302±0.0052	0.2419±0.0025
r_1 side	0.4838±0.0047	0.3412±0.0059	0.2442±0.0026
r_1 back	0.5180±0.0067	0.3548±0.0071	0.2454±0.0026
r_2 pole	0.3025±0.0049	0.2952±0.0054	0.1494±0.0034
r_2 side	0.3183±0.0062	0.3049±0.0062	0.1506±0.0035
r_2 back	0.3669±0.0127	0.3232±0.0082	0.1534±0.0038
$\Sigma(O-C)^2$	0.13586	0.07593	0.00947

the primary star luminosity (L_1). Table 2 lists the accepted models for the studied systems with the estimated parameters.

3.1. *V1264 Cas*. Light curves of the system V1264 Cas in BVRI pass bands were analyzed using the WD code [7] under the condition of Mode 3 (over contact). Trials were made to estimate the set of parameters which represent the observed light curves. Best photometric fitting was reached after several runs, which shows that the primary component is hotter than the secondary one. The accepted model reveals parameters listed in Table 2, while Fig.5 displays the observed light curves of the system V1264 Cas together with the synthetic curves in BVRI pass bands. According to the accepted orbital solution, the components of the system V1264 Cas are of spectral types K1 and K2, respectively, (Popper [13]).

3.2. *V0664 Lac*. First CCD observations for the binary system V0664 Lac in VI pass bands were analysed using Mode 2 (detached) of the WD code [7]. Mass ratio q was adopted, as mentioned before, using a q-search method (see Fig.4b). An acceptable model was assumed after some trials with the adjustable parameters as listed in Table 2, which show that the primary component of the system V0664 Lac is hotter than the secondary one. According to the adopted temperatures T_1 and T_2, the primary and secondary components are of spectral

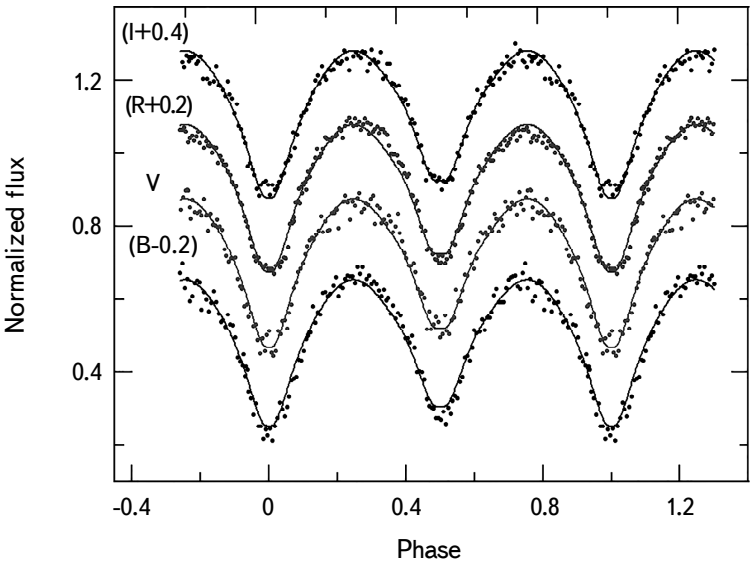

Fig.5. Synthetic (lines) and observed (dots) light curves for the system V1264 Cas.

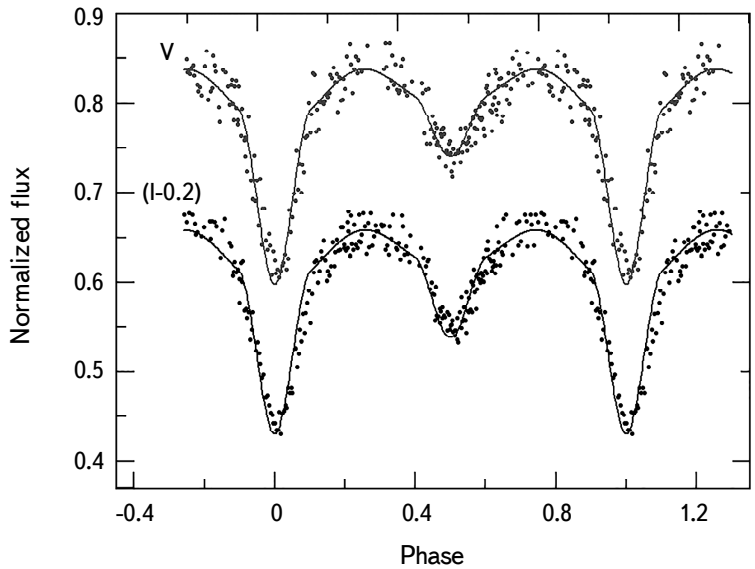

Fig.6. Synthetic (lines) and observed (dots) light curves for the system V0664 Lac.

types G3 and K5, respectively, (Popper [13]). Fig.6 presents the observed light curves together with synthetic light curves obtained by the model in VI pass bands.

3.3. *GSC 0199-2035.* Orbital solution of the discovered Algol system GSC 0199-2035 was carried out using the observed light curves in BR (Bessell) pass bands using Mode 2 (detached) of the WD code [7]. Photometric solution

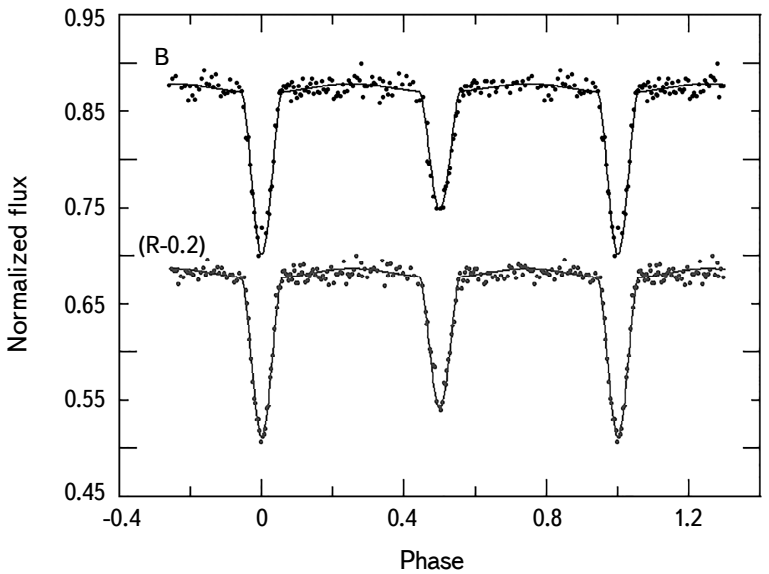

Fig.7. Synthetic (lines) and observed (dots) light curves for the system GSC 0199-2035.

parameters are listed in Table 2, it turns out that the spectral types of the primary and secondary components are K1 and K3, respectively, (Popper [13]. The adopted temperatures showed that the primary component of the system GSC 0199-2035 is hotter than the secondary one. Fig.7 displays the reflected observed points in BR (Bessell) pass bands together with the corresponding theoretical light curves obtained by the model.

The main source of data used in estimating the physical parameters of the eclipsing binary components came from spectroscopic observations of the radial velocity. Since the studied systems are new discovered systems, there are no previous spectroscopic observations, therefore, the absolute physical parameters of the systems were estimated using effective temperature-mass (T_{eff}- M) relation given by Harmanec [14]. Table 3 lists the calculated absolute physical parameters of the components of the systems V1264 Cas, V0664 Lac and GSC 0199-2035. The parameters show that all the primary components of the studied systems are massive than the secondary components. The calculated parameters assumed by the acceptable models were used in the software Package Binary Maker 3.03 (Bradstreet and Steelman [15] to display the geometric structure of the studied systems as shown in Fig.8.

4. *Evolutionary states*. The physical parameters estimated in Table 3 were used to study the evolutionary states of the studied systems by means of mass-radius (M-R) relation for zero age main sequence (ZAMS) and terminal age main sequence (TAMS). Luminosity-effective temperature (L-$T_{\rm eff}$) relation of non-

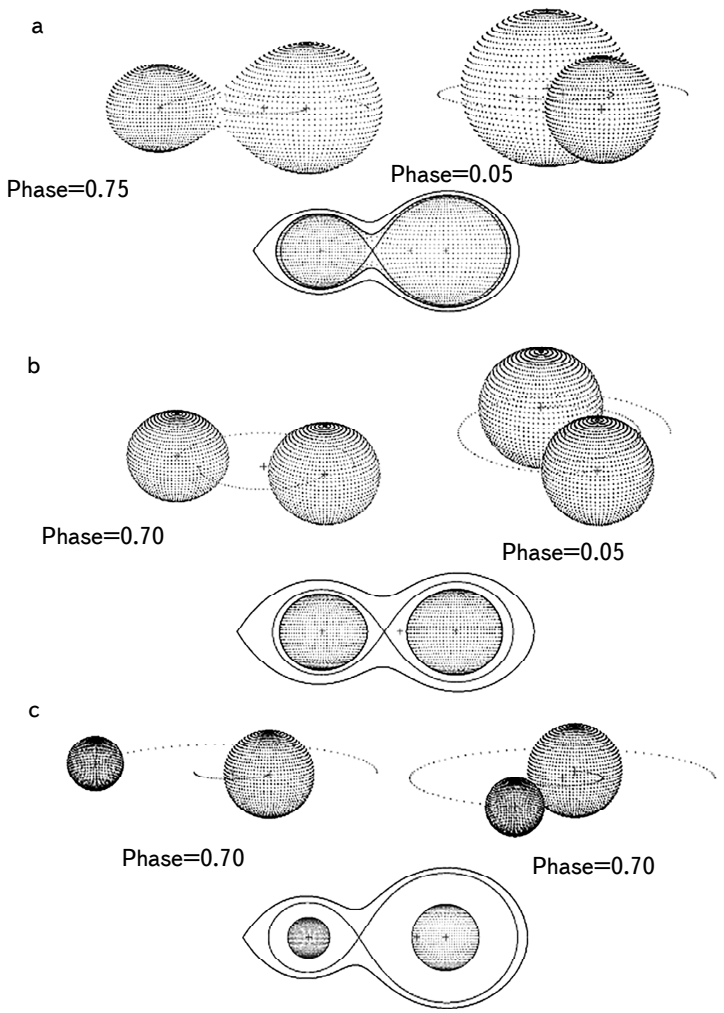

Fig.8. Three dimensional structure of the binary systems a) V1264 Cas, b) V0664 Lac, and c) GSC 0199-2035.

rotated models and the empirical mass-effective temperature (M-$T_{\rm eff}$) relation of the intermediate and low mass eclipsing binaries were used. We also used the evolutionary tracks computed by Girardi et al. [16] for both ZAMS and TAMS main sequences with metalicity $z = 0.019$. Fig.9a, b displays the locations of the components of the studied systems on the curve of mass-radius M-R and mass-luminosity M-L relations. The figures show that all the components of the studied systems located near the ZAMS track except for the secondary components of the systems; V1264 Cas and GSC 0199-2035 where they lie above the TAMS track.

Table 3

ABSOLUTE PHYSICAL PARAMETERS FOR THE SYSTEMS V1264 Cas, V0664 Lac AND GSC 0199-2035

Parameter	Star name		
	V1264 Cas	V0664 Lac	GSC 0199-2035
$M_1 / M_\odot$	0.8530±0.0348	1.0851±0.0443	0.8446±0345
$M_2 / M_\odot$	0.3466±0.0142	0.7724±0.0315	0.2241±0.0092
$R_1 / R_\odot$	0.9492±0.0388	1.1825±0.0483	0.9405±0.0384
$R_2 / R_\odot$	0.8953±0.0366	0.7213±0.0295	0.8465 ±0.0346
$T_1 / T_\odot$	0.8702±0.0355	0.9869±0.0403	0.8660±0.0354
$T_2 / T_\odot$	0.8446±0.0345	0.7641±0.0312	0.8217±0.0336
$L_1 / L_\odot$	0.5159±0.0211	1.3243±0.0541	0.4969±0.0203
$L_2 / L_\odot$	0.4073±0.0166	0.1771±0.0072	0.3263±0.0133
M_{bol1}	5.4685±0.2233	4.4450±0.1815	5.5093±0.2249
M_{bol2}	5.7252±0.2337	6.6294±0.2706	5.9660±0.2436
Sp. Type	$(K1)^1$, $(K2)^2$	$(G3)^1$, $(K5)^2$	$(K1)^1$, $(K3)^2$

Note: The subscript/superscript 1 and 2 refers to the primary and secondary components, respectively.

Deviation in the locations of the secondary's components of the systems V1264 Cas and GSC 0199-2035 can be ascribed to energy transfer from the primary to the secondary component of the two systems through the common convective envelope as suggested by Lucy [17]. Using the non-rotating evolutionary models

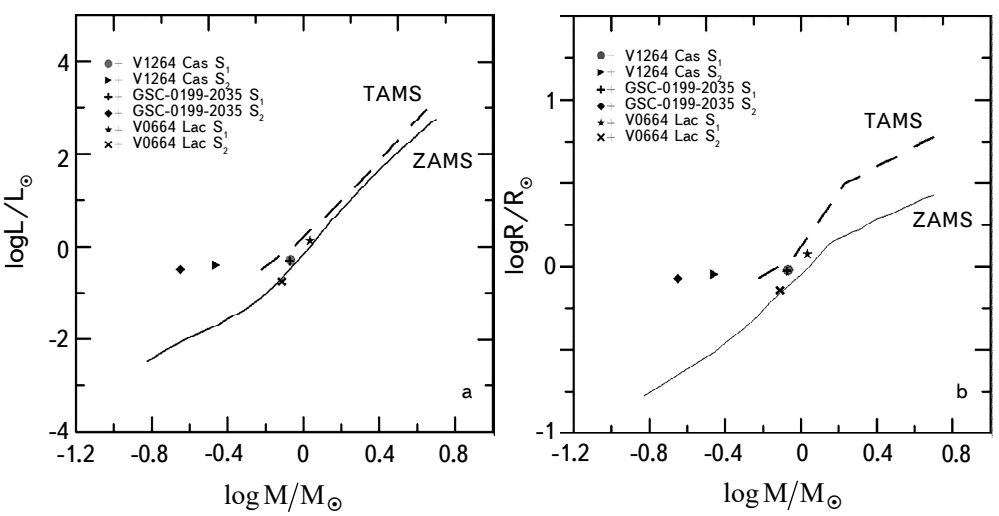

Fig.9. Positions of the components (S1, S2) of the systems V1264 Cas, V0664 Lac and GSC 0199-2035 on the theoretical: mass-luminosity diagram (a) and mass-radius diagram (b) of Girardi et al. [16].

of Ekstrom et al. [18] at solar metallicity $z=0.014$, the components of the studied systems were assigned on the ($T_{\rm eff}$ - L) relation as shown in Fig.10, where all components of the studied systems lie on the expected tracks.

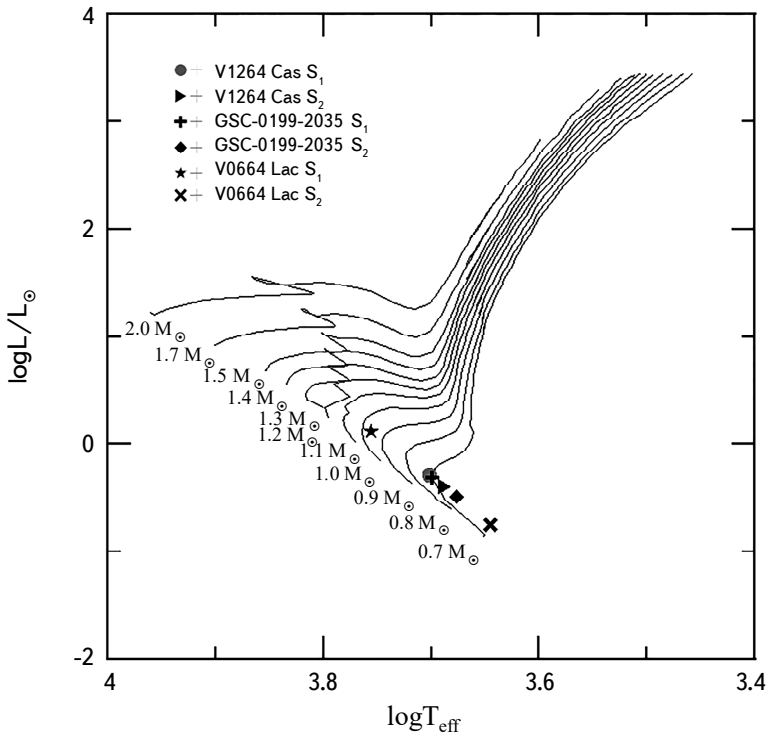

Fig.10. Positions of the components (S1, S2) of the systems V1264 Cas, V0664 Lac and GSC 0199-2035 on the effective temperature-luminosity diagram of Ekstrom et al [16].

Fig.11 displays the mass-effective temperature relation (M - $T_{\rm eff}$) for intermediate and low-mass stars (Malkov [19]) for the components of the systems. Locations of the systems components on M - $T_{\rm eff}$ diagram have a good fit except for the secondary's components of the systems V1264 Cas and GSC 0199-2035. It's clear that the same components have the same behaviour in terms of mass-luminosity and mass-radius relations, as shown in Fig.9, where we ascribed such behaviour to an energy transfer from the primary to the secondary component of the two systems through the common convective envelope as suggested by Lucy [17].

5. *Discussion and conclusion*. First orbital solutions were carried out for the new discovered eclipsing binary systems V1264 Cas, V0664 Lac and GSC 0199-2035 by means of CCD observations in different pass bands. A set of absolute parameters were estimated, which showed that the primary components of all

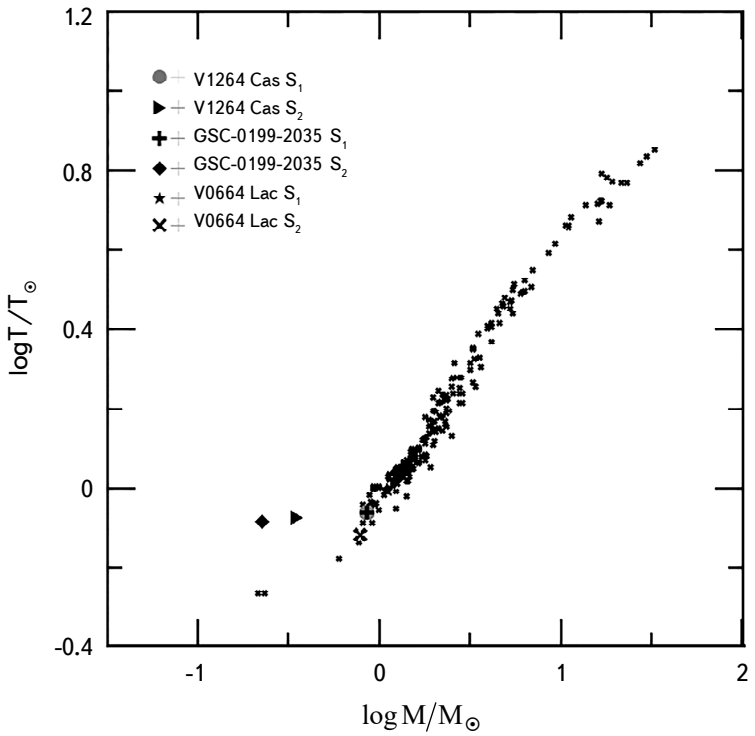

Fig.11. Positions of the components (S1, S2) of the systems V1264 Cas, V0664 Lac and GSC 0199-2035 on the empirical mass - T_{eff} relation for low-intermediate mass stars by Malkov [19].

studied systems are hotter and more massive than the secondary components. The spectral types of the systems components were assigned according to the estimated temperatures. Behaviour of the studied systems components in terms of *M-L* and *M-R* relations was investigated to explore their evolutionary states. It is found that all the components of the studied systems are located near ZAMS track except for the secondary components of the systems V1264 Cas and GSC 0199-2035, which we attributed to energy transfer from the primary to the secondary component of these two systems through the common convective envelope.

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ПЕРВОЕ МОДЕЛИРОВАНИЕ КРИВЫХ БЛЕСКА ЗАТМЕННО-ДВОЙНЫХ СИСТЕМ V1264 Cas, V0664 Lac И GSC 0199-2035

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Фотометрический анализ недавно обнаруженных систем V1264 Cas, V0664 Lac и GSC 0199-2035 был проведен с использованием самой последней версии кода моделирования двойных звезд Уилсона-Девинни (WD), основанного на моделях атмосфер Куруца. Принятые модели используют выявленные физические параметры для определения спектрального класса компонентов исследуемых систем. Расположение систем по теоретическим соотношениям масса-светимость и масса-радиус выявило хорошее соответствие для всех компонентов систем, кроме второстепенных компонентов систем; V1264 Cas и GSC 0199-2035, где они лежат над последовательностью TAMS.

Ключевые слова: *затменно-двойные системы:моделирование кривой блеска: эволюционное состояние*

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